Surface erythemal UV irradiance in the continental United States derived from ground-based and OMI observations: quality assessment, trend analysis and sampling issues

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Compilation and spatio-temporal analysis of publicly available total solar and UV irradiance data in the contiguous United States☆

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Environmental Pollution, 253, 130-140, 2019.

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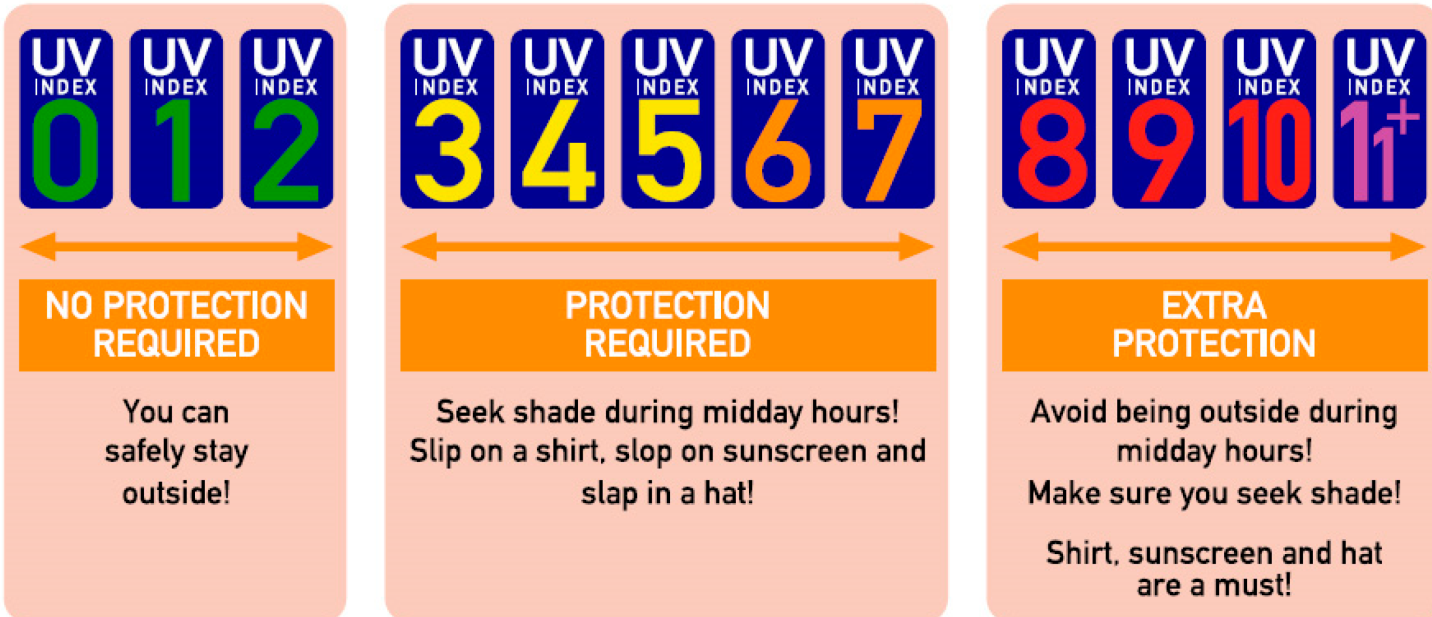
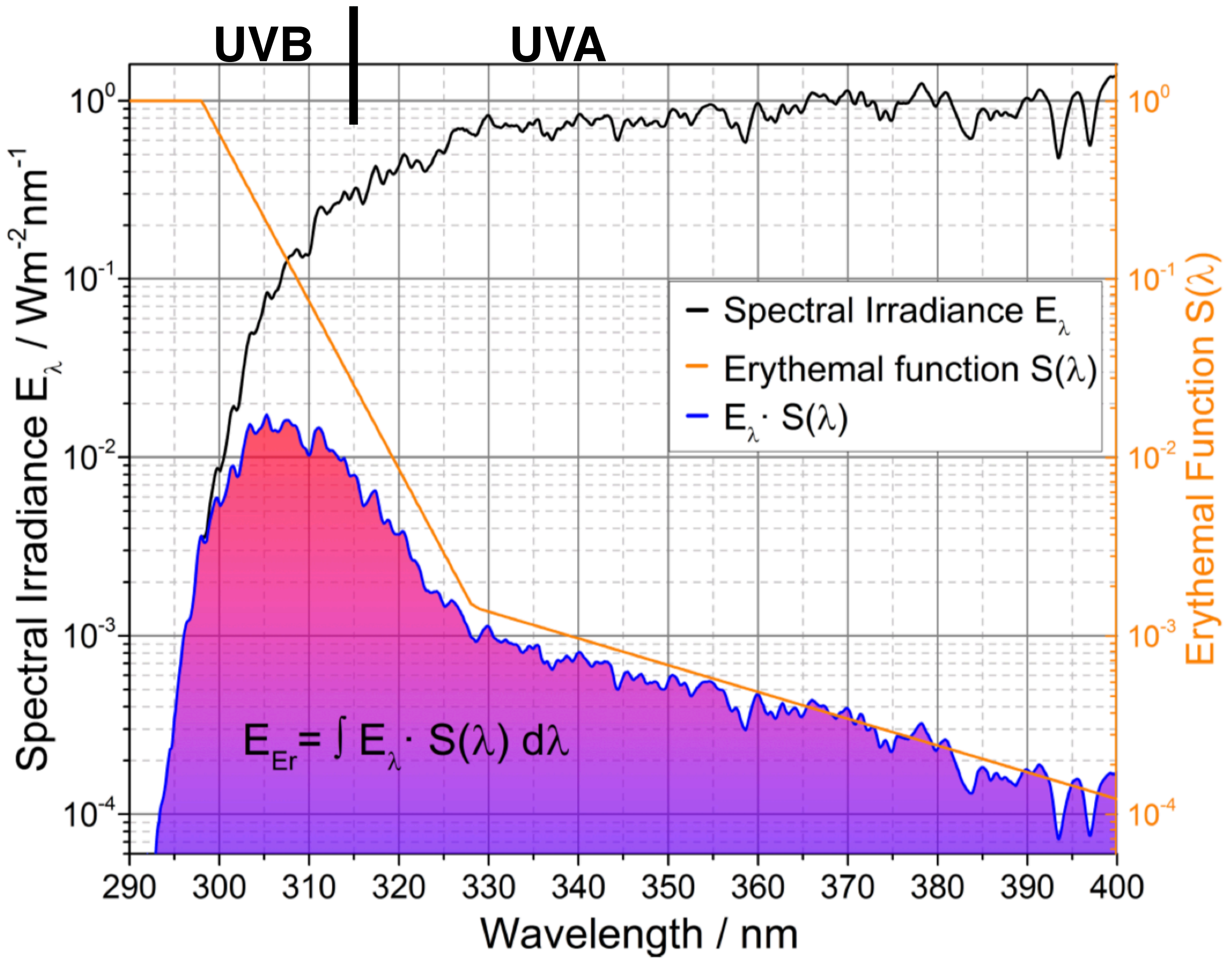
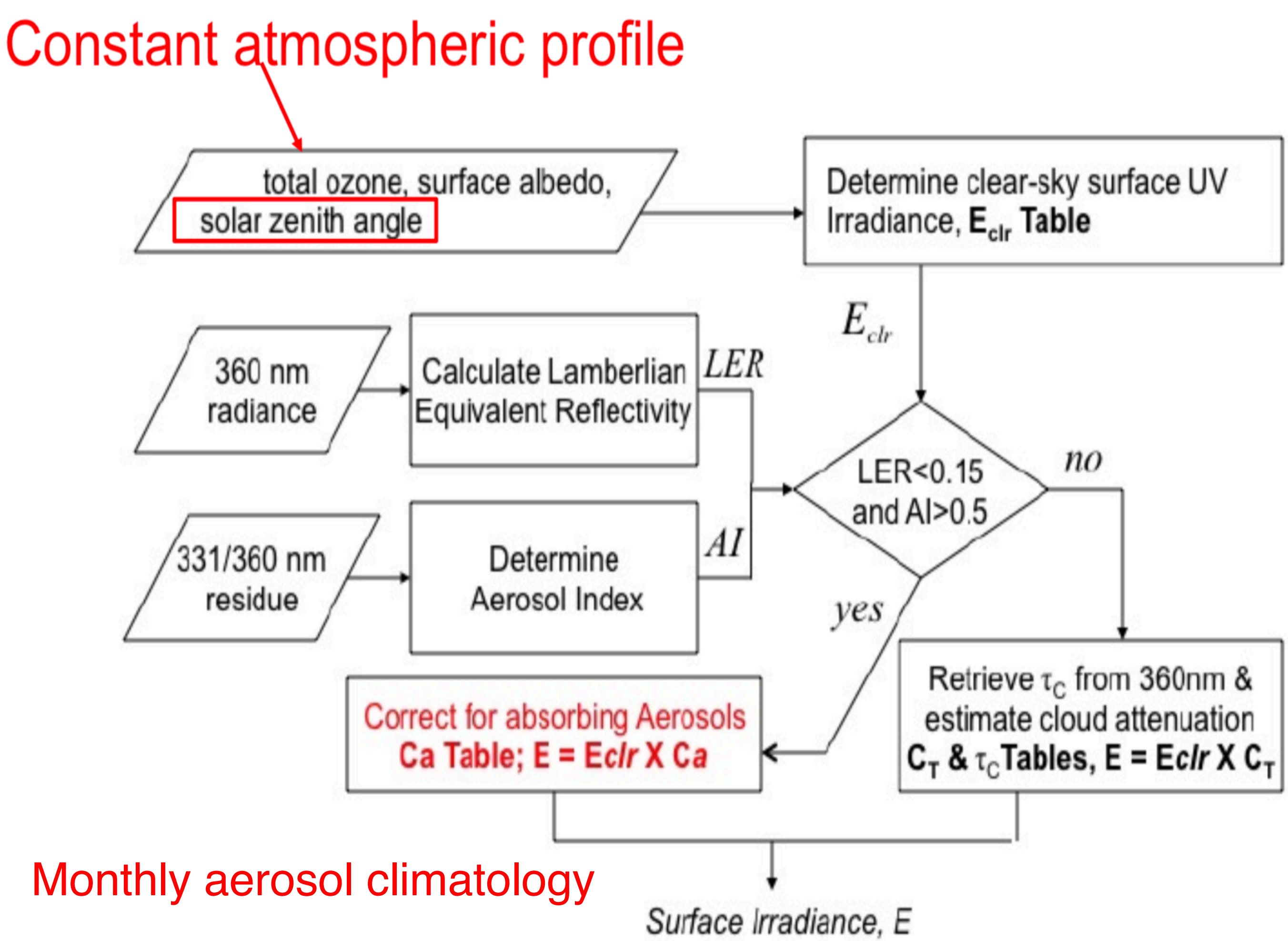
WHO guidance, also recommended by EPA



UV Index = Erythemal Weighted Irradiance / 25 mWm^{-2}



OMI surface UV data product

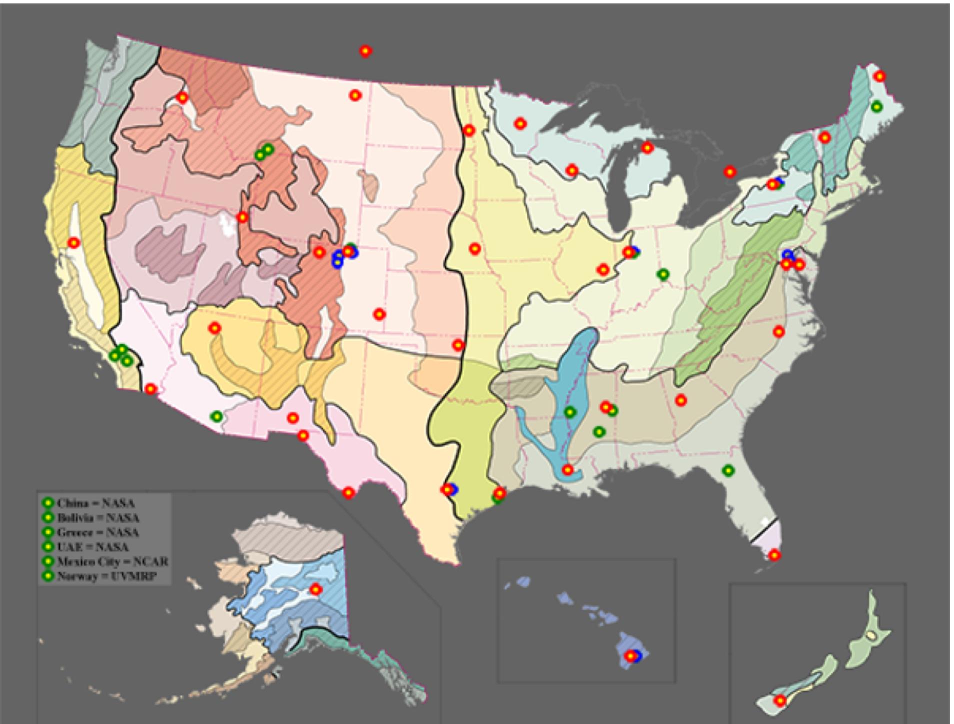


Arola et al., 2009

- Spectral irradiance at 305, 310, 324, 380 nm
- Erythemal Dose Rate (**EDR**) full-sky local solar noon time (Noon_FS), full-sky satellite overpass time (OP_FS)
- Erythemally weighted Daily Dose (Jm-2): **EDD**
- Level 2 products, 13 x 24 km^2 at nadir

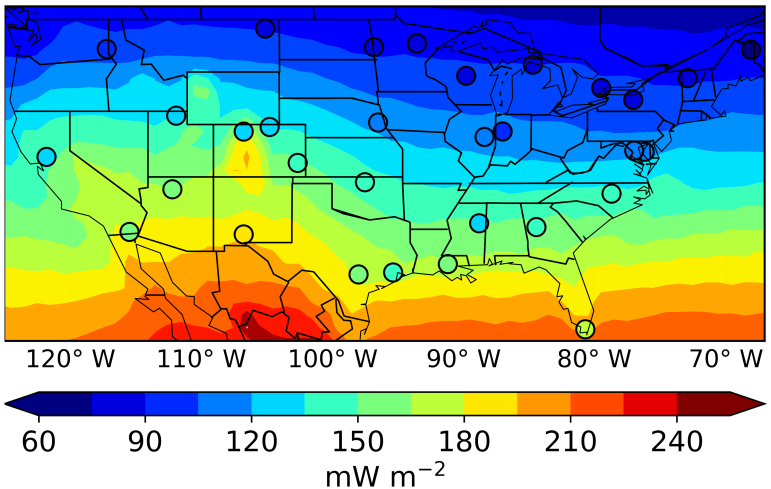
USDA UV Monitoring & Research Program
UVMPR network

3-minute averaged data from 31 stations in 2005 – 2017 are used for this study



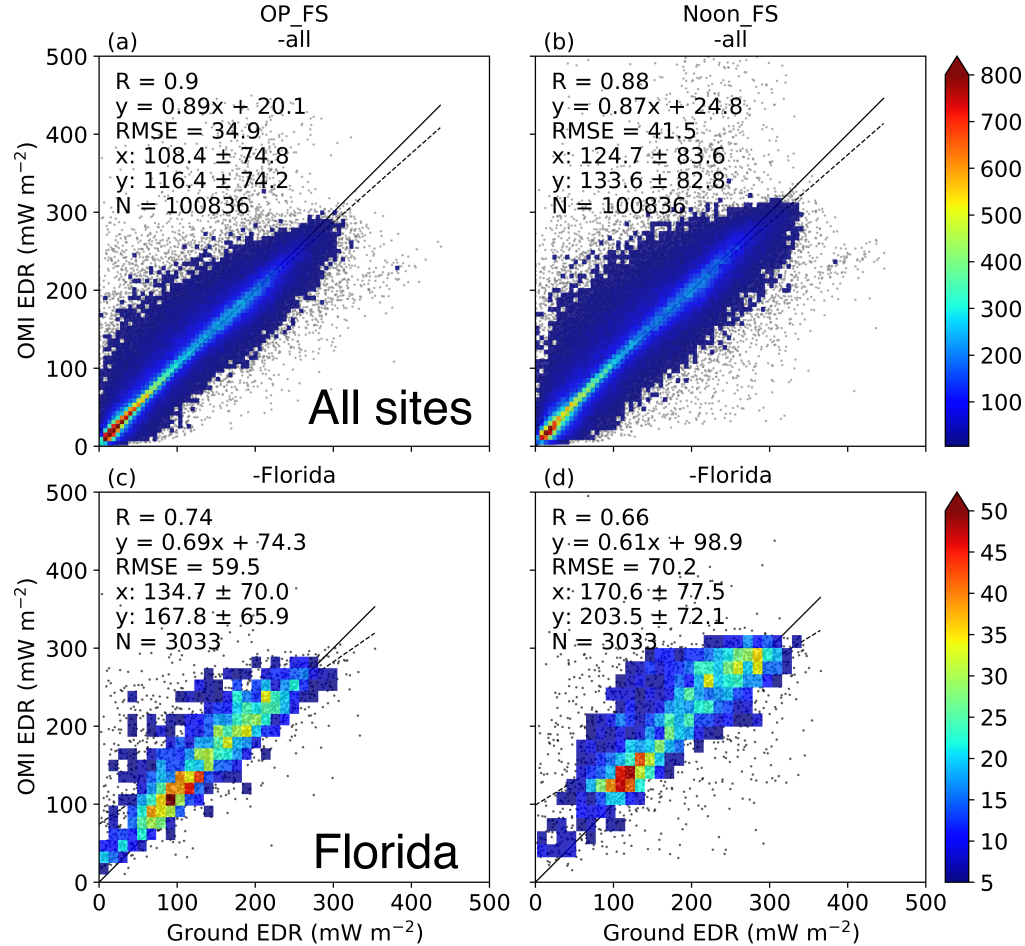
(http://uvb.nrel.colostate.edu/UVB/index.jsf)

Jan. 2005 – Dec. 2017



OMI overpass time

Noontime



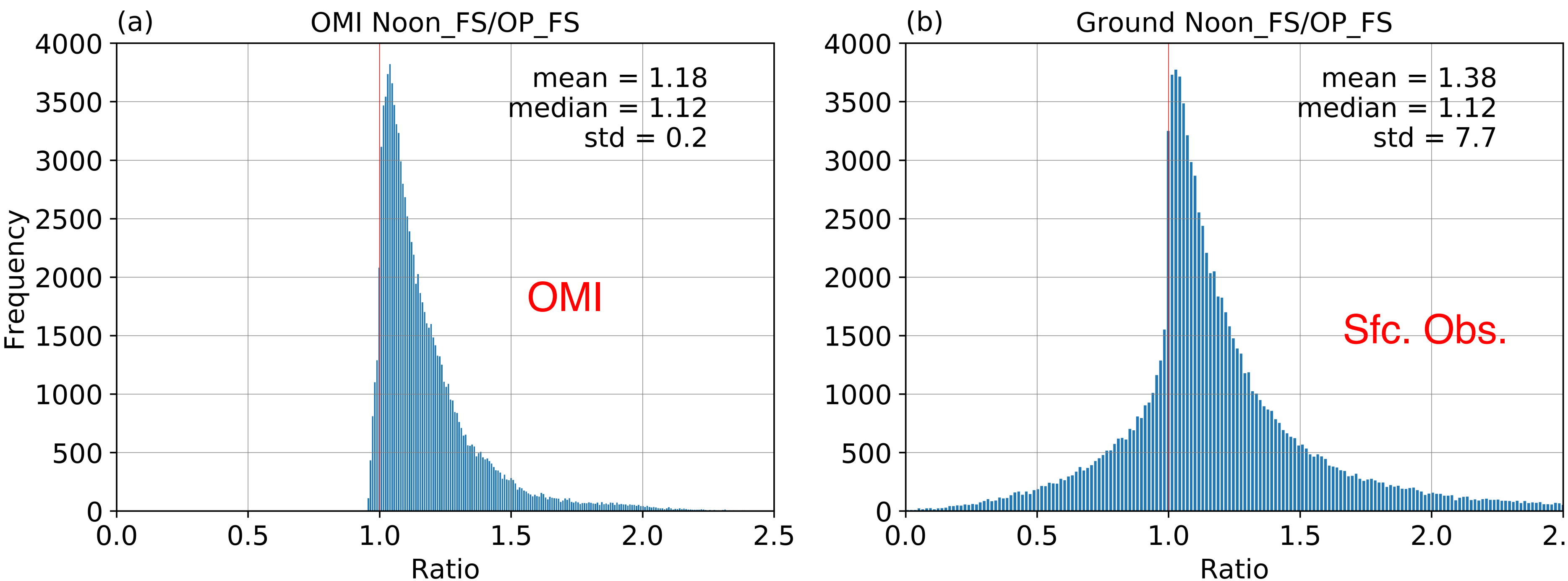
Overall, R ~ 0.9 and bias by +7%.

Vary by station. Worst in Florida (R ~ 0.7; bias: +20%).

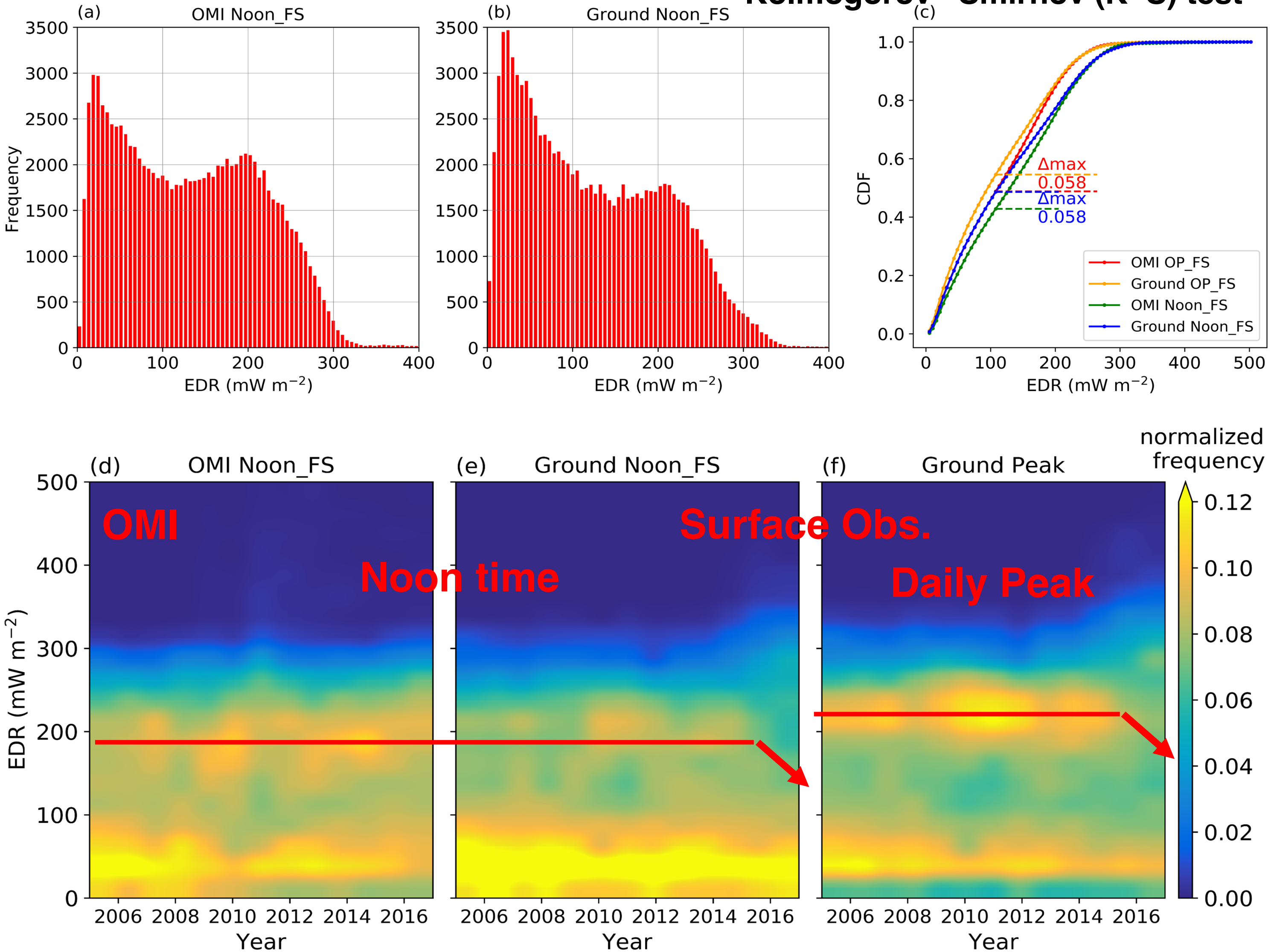
Peak UV doesn't necessarily occurs in noontime

- suggesting the importance of diurnal variation, likely to be resolved by geo-satellite such as TEMPO.

Noon vs. overpass time EDR ratio



Kolmogorov– Smirnov (K–S) test



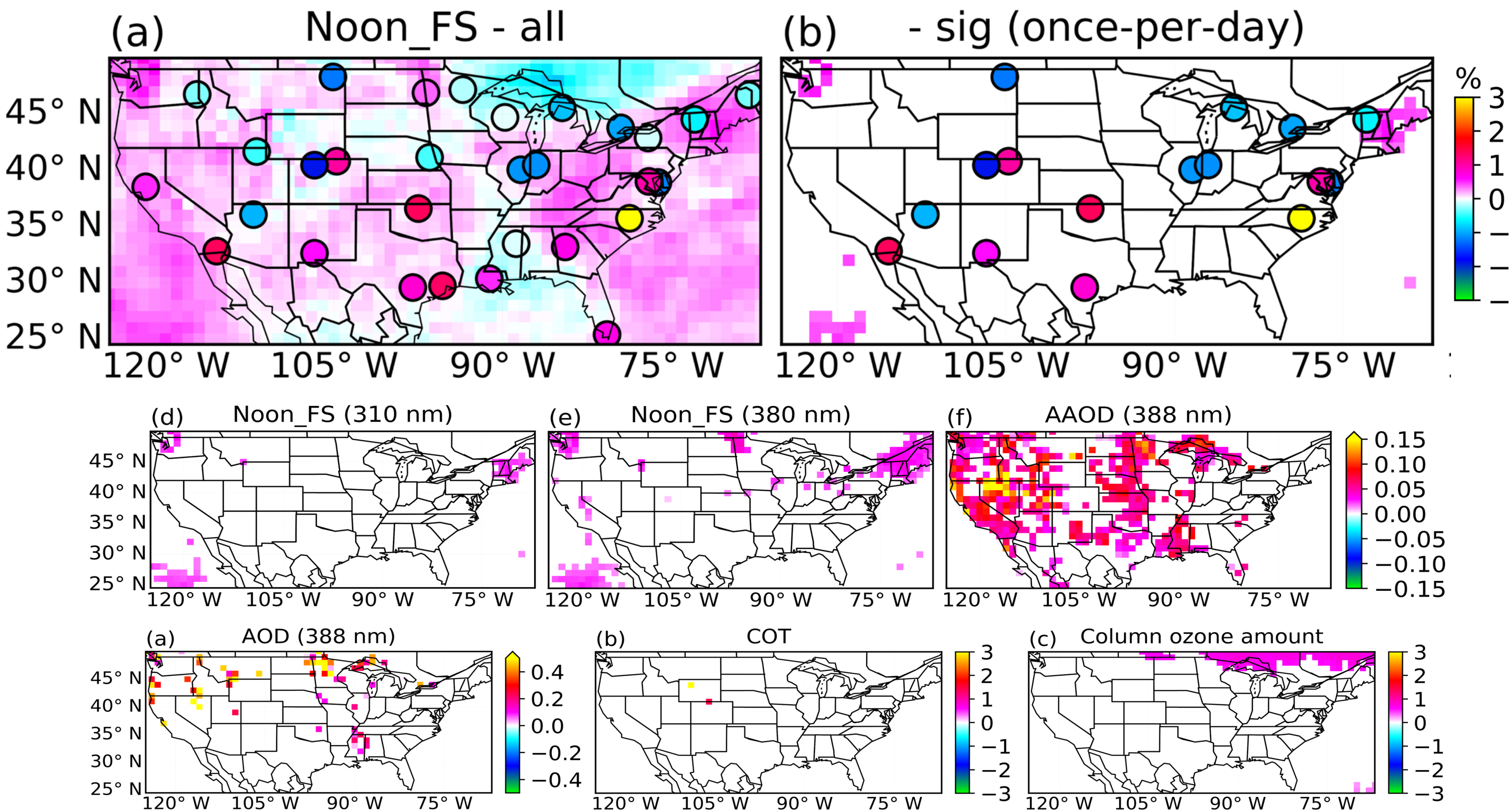
Statically significant agreement in CDF.

Daily peak is not necessarily at solar local noon

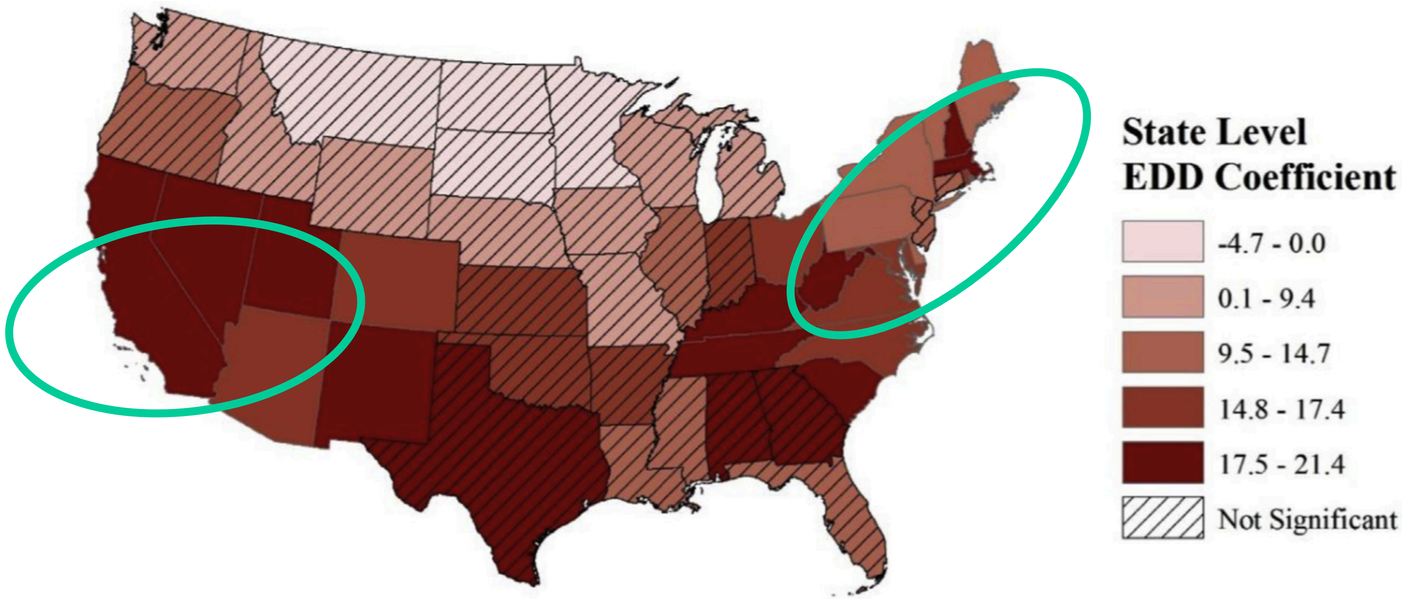
The peak weakens after 2015, but not seen by OMI

Trend Analysis

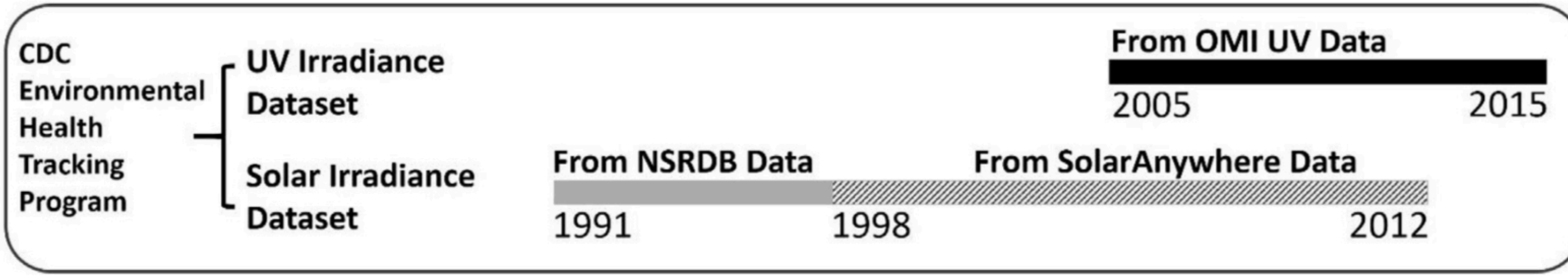
After de-seasonalize & auto-regression removal

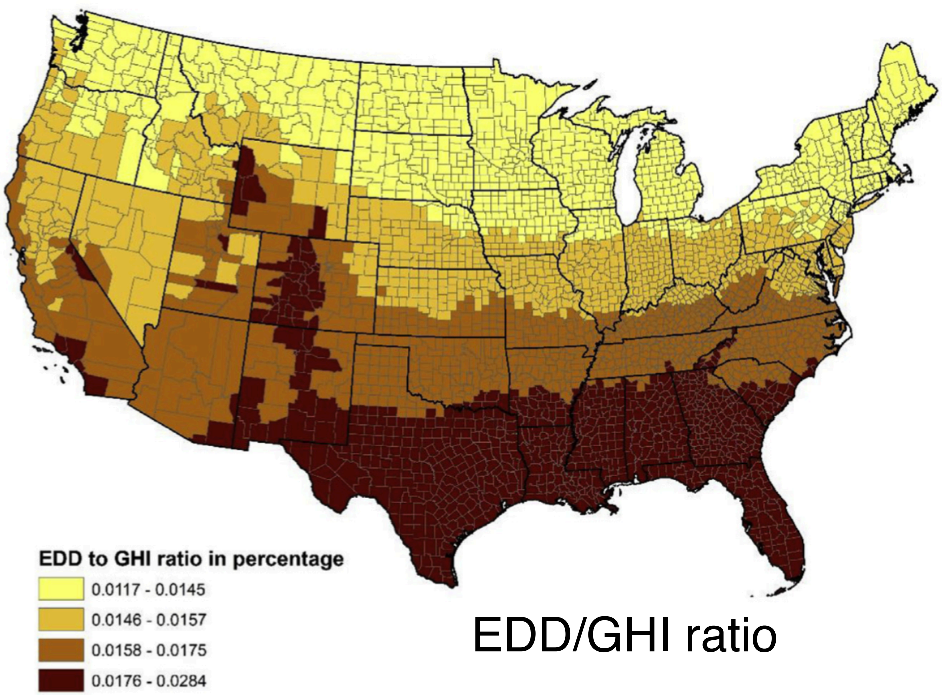


Trends of population-weighted annual UV exposure in 2005-2017 for each state



- Overall, an increase in most states. Statistically significant trend can be found in southwest states (California, Arizona, Mexico, Nevada, Utah and Colorado) and east coast states.
- Appears to support that “In 1994 - 2014, the diagnosis and treatment of nonmelanoma skin cancers increased by 77%”. https://www.skincancer.org/





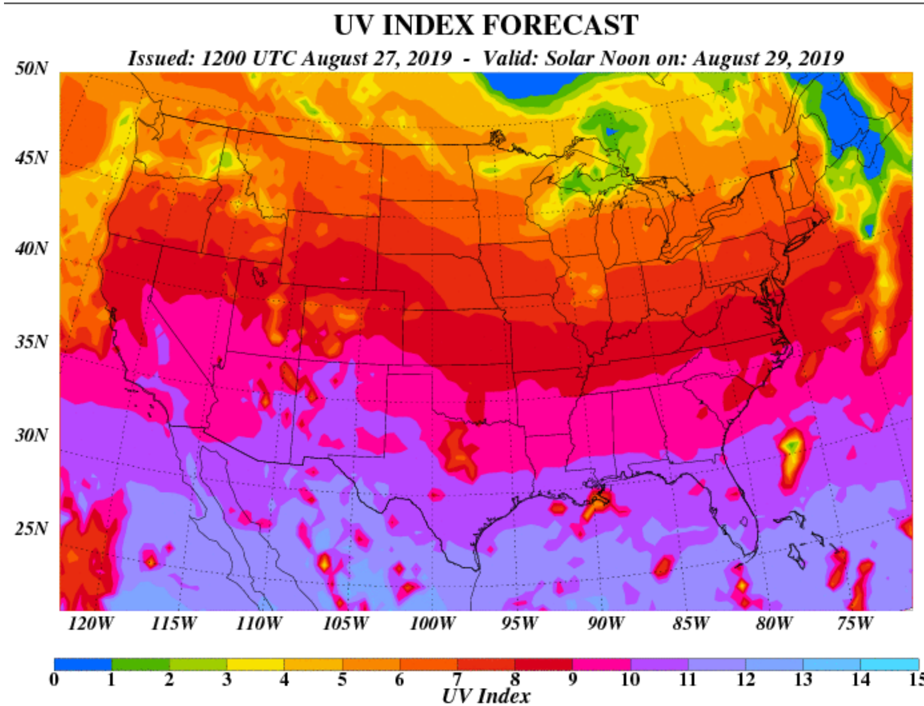
EDD/GHI ratio

In the past, solar irradiance data is used to estimate surface UV irradiance by using a constant conversion ratio. But, this ratio changes with location and time.

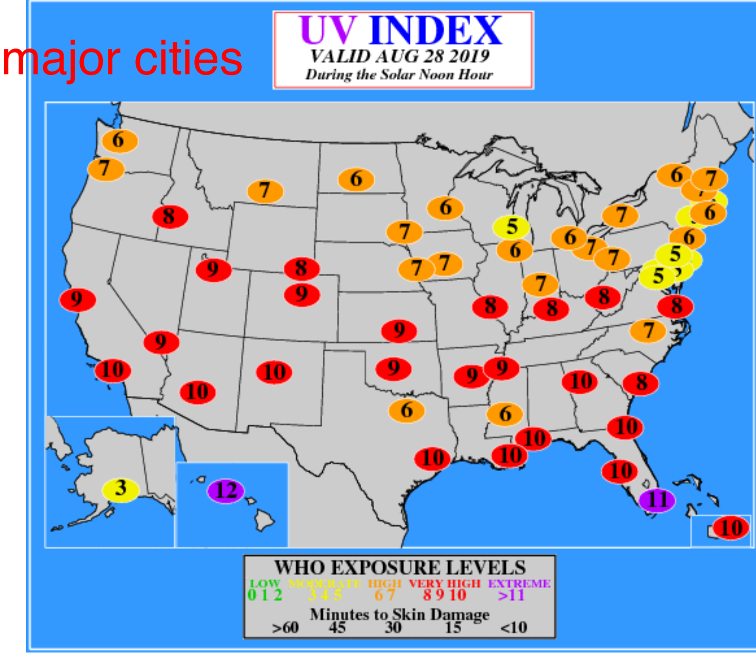
OMI surface erythemal data is now used in CDC health track data portal.

Summary

- Overall, OMI's EDR climatology (CDF) is statistically consistent with that revealed in situ observations for 31 surface rural sites, but OMI's EDR doesn't represent the peak of EDR as seen by surface observations → temporal bias and more robust trend analysis likely to be addressed by geo-satellites (TEMPO)
- Overall, OMI's EDR has 7% positive bias, larger than 6% uncertainty in surface observations.
- OMI's EDR shows increasing trend in west, southeast and southwest U.S., but not at statistically significant level. The trends can not be explained by cloud, O3, AOD, or AAOD from OMI, although they agree with surface observations at some (but not all) sites.
- OMI EDR is now in the CEC's Health Tracking system. Population-weighted UV exposure show increase in CA, SC, NC, and VA, what are somewhat consistent with surface obs.
- Evaluating EDR since TOMS era is needed for exposure studies as well as trend analysis.



50 major cities

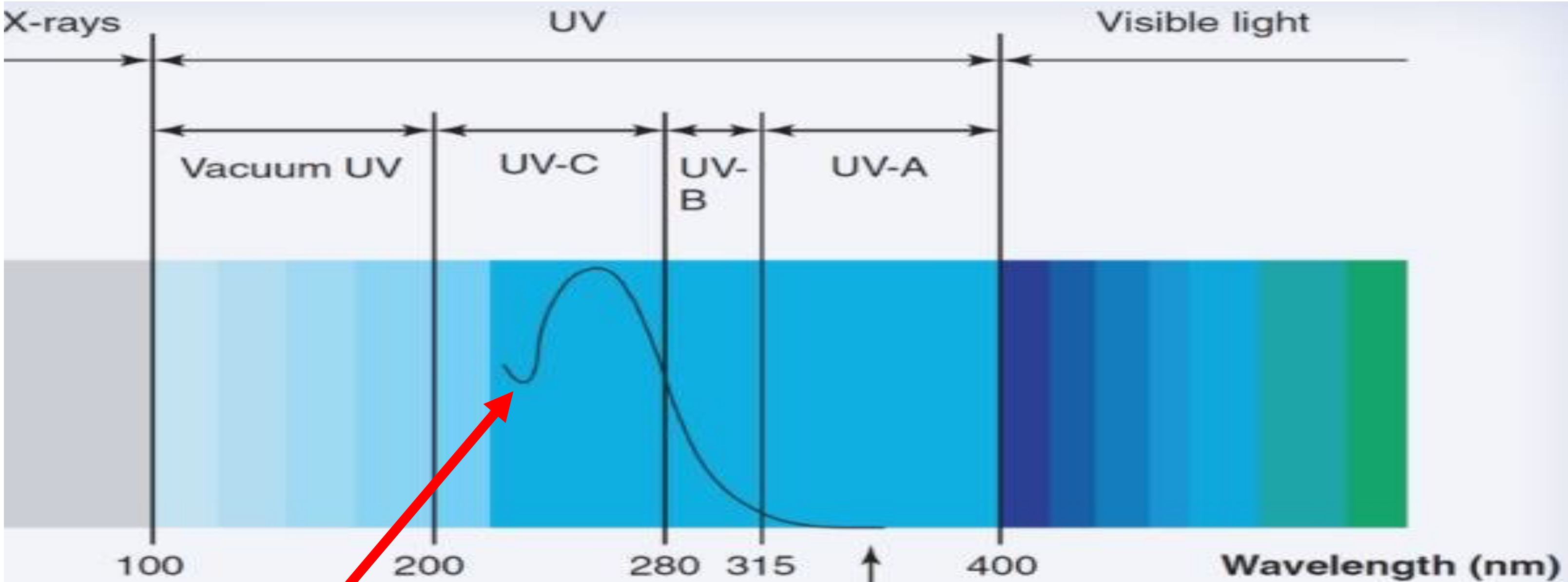


(U.S.EPA sun safety program & NOAA NWS)

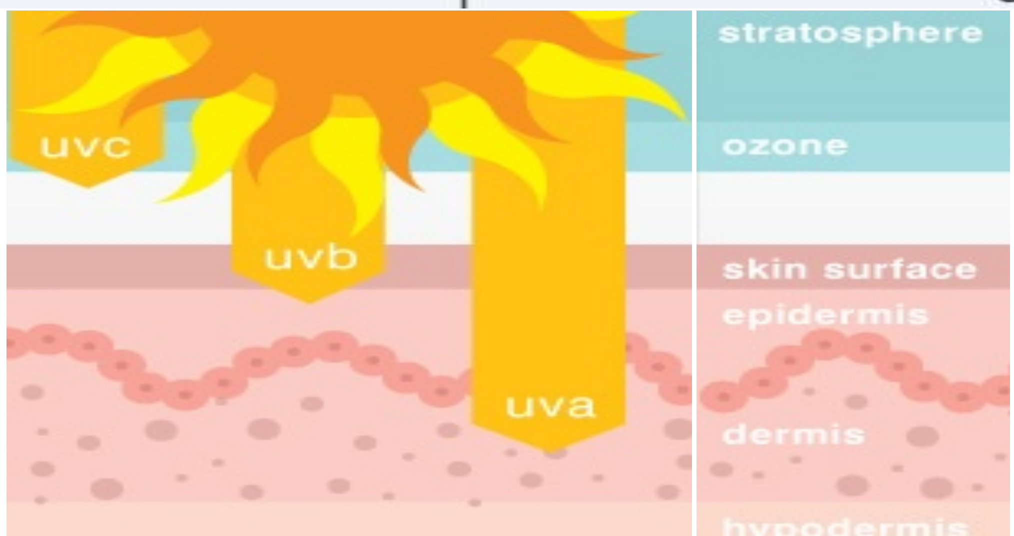
SKY	9am	10am	11am	12pm	1pm	2pm	3pm	4pm
UV Index	3	4	6	8	9	8	6	4
Cloud Cover	0%	0%	0%	0%	0%	0%	0%	0%
Humidity	57%	49%	45%	43%	40%	38%	37%	36%
Dew Point	59°	58°	59°	62°	62°	61°	61°	59°
Visibility	10 mi	10 mi	10 mi	10 mi	10 mi	10 mi	10 mi	10 mi

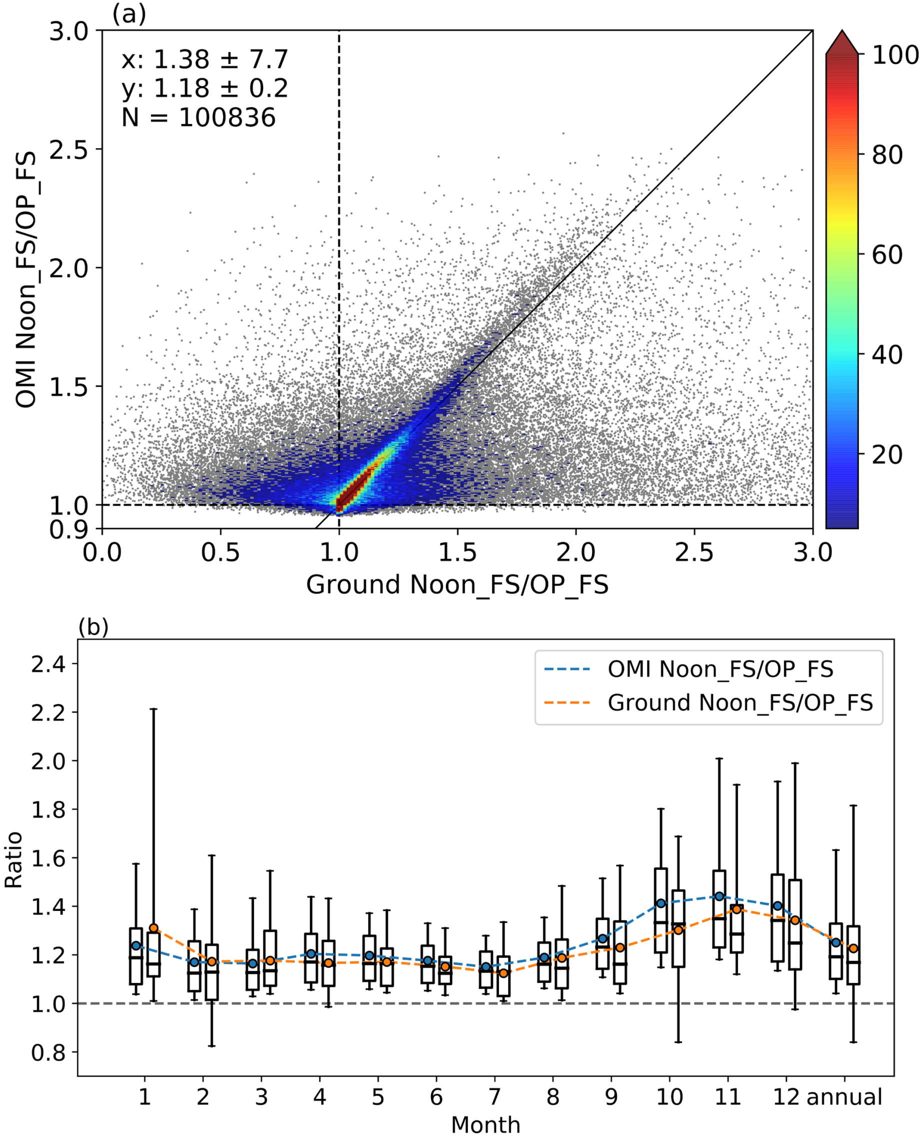
Accuweather.com

Tuesday forecast for Thursday



spectral curve of cell inactivation




(a)
x: 1.38 ± 7.7
y: 1.18 ± 0.2
N = 100836
OMI Noon_FS/OP_FS
Ground Noon_FS/OP_FS
3.0
2.5
2.0
1.5
1.0
0.9
0.0
0.5
1.0
1.5
2.0
2.5
3.0
100
80
60
40
20
(b)
OMI Noon_FS/OP_FS
Ground Noon_FS/OP_FS
Ratio
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
1
2
3
4
5
6
7
8
9
10
11
12
annual
Month

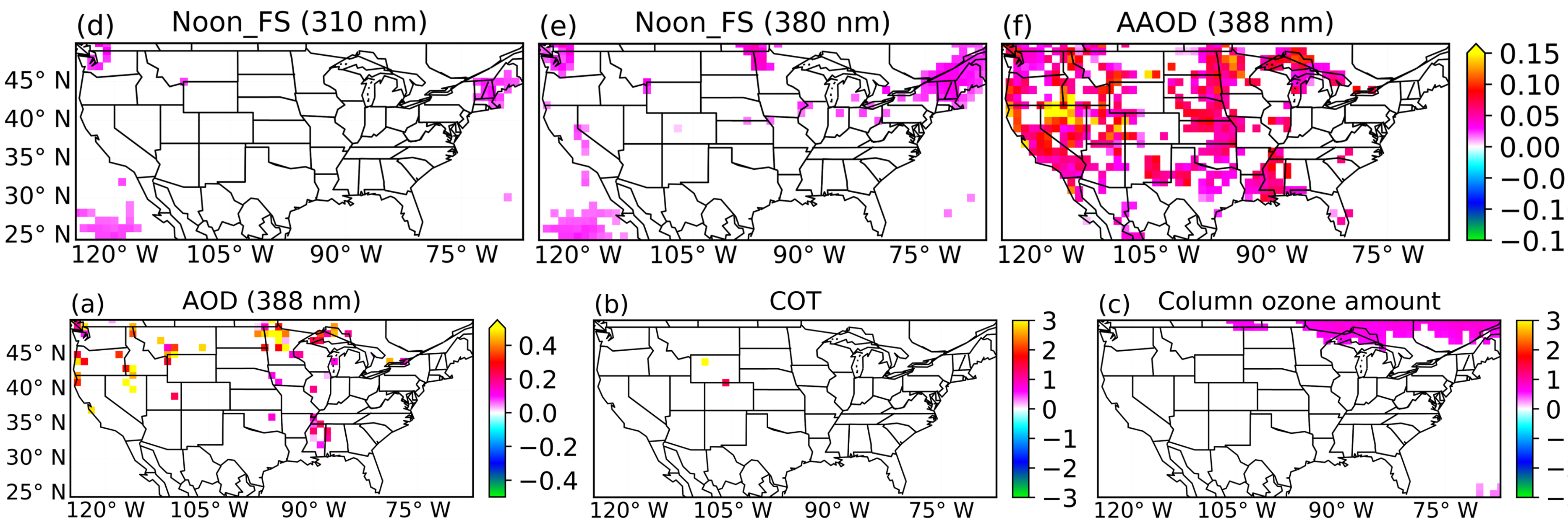
Trend Analysis

After De-seasonalize, auto-regression removal

$$Y_t = C + S_t + \omega X_t + N$$

$$N_t = \phi N_{t-1} + \varepsilon_t$$

$$S_t = \sum_{j=1}^{4} \left[\beta_{1,j} \sin(2\pi jt/12) + \beta_{2,j} \cos(2\pi jt/12) \right]$$



In the U.S.

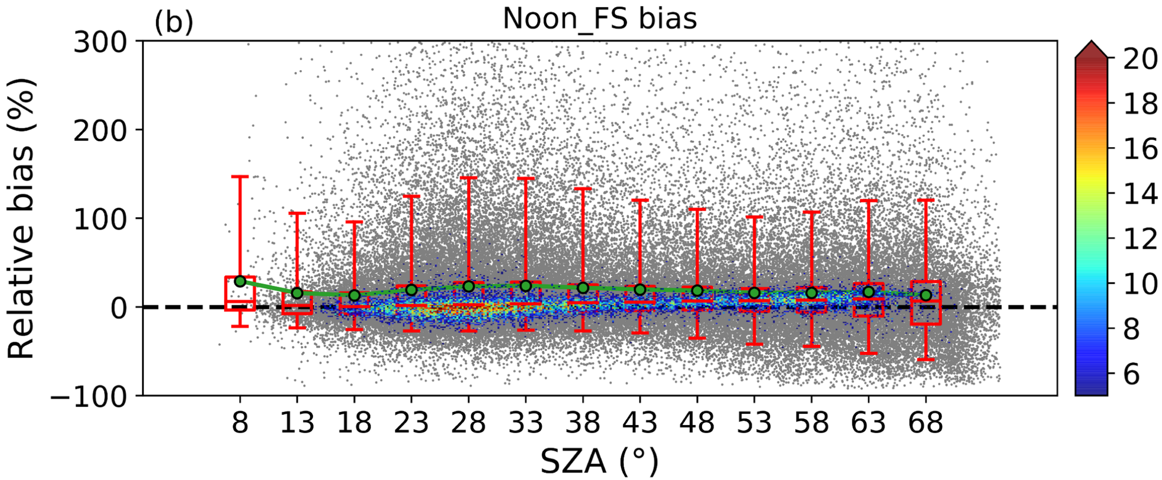
- **More people** are diagnosed with skin cancer each year in the U.S. than all other cancers combined.
- **One in five Americans** will develop skin cancer by the age of 70
- **More than 2 people** die of skin cancer every hour
- In 1994 - 2014, the diagnosis and treatment of nonmelanoma skin cancers increased by 77%. ~ 90 percent of nonmelanoma skin cancers are associated with exposure to ultraviolet (UV) radiation from the sun
- In 2009 – 2019, the number of new invasive melanoma cases diagnosed annually increased by 54%. Having **5 or more sunburns** doubles the risk for melanoma.

https://www.skincancer.org/

sunburns

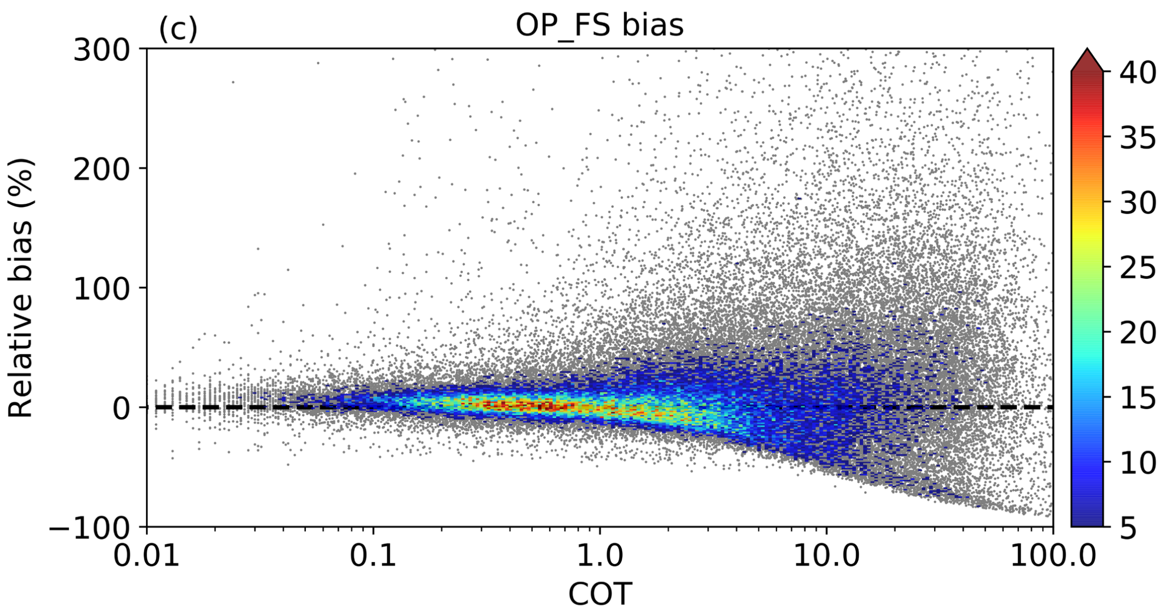
Nonmelanoma skin cancer

melanoma



Bias shows :

little dependence on SZA



larger bias as COT increases

Importance of temporal sampling for trend analysis